

Table V.

Gas.	Molecular diameter (in cm. $\times 10^8$).	Molecular volume (in cm. ³ $\times 10^{22}$).
Chlorine	3.15	1.30
Bromine	3.36	1.59

Apparently the dimensions of the molecules do not differ to any great extent, and this, of course, involves that the density of the atom of bromine is something like twice as great as that of chlorine.

The Hall Effect in Liquid Electrolytes.

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(Communicated by Sir J. J. Thomson, O.M., F.R.S. Received May 8,—
Read June 19, 1913.)

Introduction.

The distortion of the lines of flow of an electric current in a thin metal plate by the action of a magnetic field was discovered in 1879.* Hall attributed this to the action of the magnetic field on the molecular currents in the metal film, which were deflected to one side or the other and accompanied by a corresponding twist of the equipotential lines. This explanation did not pass without criticism, and another theory of the effect found by Hall was published in 1884.† In that paper the author seeks to explain the effect by assuming a combination of certain mechanical strains and Peltier effects, a thermo-electric current being set up between the strained and the unstrained portions. The effect of such strain was to produce a reverse effect in some metals, and these were precisely the metals for which the Hall effect was found to reverse. Aluminium was the only exception.‡

In other respects, however, as shown by Hall in a later paper,§ Bidwell's

* E. H. Hall, 'Amer. Journ. Math.,' vol. 2, p. 287; 'Phil. Mag.,' 1880, vol. 9, p. 225.

† S. Bidwell, 'Roy. Soc. Proc.,' 1884, vol. 36, p. 341.

‡ 'Nature,' vol. 29, p. 514; 'Chem. News,' vol. 49, p. 147.

§ 'Science,' vol. 3, p. 387; 'Phil. Mag.,' 1885, vol. 19, p. 419.

theory did not stand the test of experiment, and the results lend no support to his theory, while they are in complete accordance with the explanation that the molecular currents are disturbed by the action of the magnetic field. On the electron theory of metallic conduction, the mechanism of the Hall effect is more obvious, but at present no satisfactory explanation of the reversal found in some metals is known. Further experiments have made it clear that there is a real deflection of the elementary currents, due to the application of the magnetic field, independent of any effect due to strain.

The first attempt to measure the Hall effect in gases was made by Marx in 1900.* The velocities of the ions from flames are about one million times the ionic velocities in liquids, and, what is very important, there is in this case a considerable difference between the velocities of the two kinds of ions. Marx succeeded in showing that a small though appreciable Hall effect existed in such flame gases and verified completely the predictions of the convective theory.

In 1902, H. A. Wilson† showed that the Hall effect was large in the positive column of the discharge tube, at low pressures, the effect being proportional to the intensity of the magnetic field.

There are certain considerations which lead us to suppose that a true Hall effect exists in liquid conductors. In the first place, a liquid conductor contains ions which, owing to their motion, constitute elementary molecular currents. In the second place, it has been established that the presence of strains is not an essential factor in the production of the effects sought. Although the effect will necessarily be small, on account of the low value of the mobility of the ions in electrolytes, still there is every reason to suppose that it does exist and that the difficulty lies in our not being able to appreciate the small effects, which are likely to be masked by disturbing forces.

Review of Past Work on Liquids.

Roiti,‡ in 1882, attempted to observe the Hall effect in a thin liquid lamina, the liquid being enclosed between two plates of glass (55 mm. $\times$ 60 mm.) separated by a distance of 0.05 mm. The results obtained were complex and difficult to interpret. Roiti holds the opinion that they are due to local variations of concentration.

In 1896 Roiti's research was repeated by Bagard,§ who claimed to establish

* 'Ann. der Phys.,' 1900, vol. 2, p. 798.

† 'Proc. Camb. Phil. Soc.,' 1902, vol. 11, p. 249.

‡ 'Atti R. Accad. Lincei,' 1882, vol. 12, p. 397.

§ 'Comptes Rendus,' 1896, vol. 122, p. 77 ; 1896, vol. 123, p. 1270.

the existence of the Hall effect to a high degree in liquids. In Bagard's experiment the liquid layer was horizontal and the bounding plates were 53 mm. $\times$ 30 mm., the distance between the plates being 1.6 mm. A water bath was used to prevent disturbances due to temperature variations. The pole pieces of the electromagnet had square plates (5 cm. side) attached to them, and the plates were separated by a distance of 2.5 cm. Bagard considered that the field was uniform in the central region of the lamina.

Here it is important to consult a research by Voigt* concerned with the alteration of the concentration of a salt solution placed in a non-uniform magnetic field. The effect of such variations of concentration, even if they occur at the boundary of the lamina only, will be sufficient, in a short time, to produce diffusion of the salt from the central region. This may give rise to a potential difference which is considerably greater than the estimated value of the Hall effect. As Roiti had found, the effect was not produced instantaneously; the rate of growth was large at first and small afterwards and varied with the concentration of the solution. Both Bagard and Roiti used a capillary electrometer to measure the transverse potential difference.

Shortly afterwards, Bagard's research was repeated by Florio,† under precisely the same conditions. He obtained a negative result, and attributed the large effects found by Bagard partly to disintegration of the electrodes and partly to disturbances produced by vibrations. The dimensions of the lamina used by Florio were 11 cm. $\times$ 10 cm. $\times$ 1.6 mm., and the pole pieces had a diameter of 13 cm.

The experiments of Bagard have been further tested by Chiavassa,‡ who took every precaution to reproduce the original conditions as accurately as possible. He concluded that the effect observed by Bagard was spurious and due to variations of temperature and of concentration, the latter being caused by non-uniformity of the magnetic field over the region occupied by the lamina. Chiavassa found that a small liquid film exposed to a uniform magnetic field gave no indication of a Hall effect. A capillary electrometer, which would detect 0.00005 volt, was used to measure the transverse potential difference.

Two more attempts have been made to discover the existence of the Hall effect in liquids. These were made in 1904 by Heilbrun§ and in 1908 by Delvalez.|| Heilbrun used a triple cathode and investigated the redistribution

* 'Gött. Nach.,' 1910, p. 545.

† 'Nuovo Cimento,' 1896, vol. 4, p. 106; 1897, vol. 6, p. 108.

‡ 'Nuovo Cimento,' 1897, vol. 6, p. 296.

§ 'Ann. der Phys.,' 1904, vol. 15, p. 988.

|| 'Journ. de Phys.,' 1909, vol. 8, p. 360.

of the deposit on each portion under the action of a magnetic field. The small variations observed were attributed to movements of the electrolyte. Delvalez used an alternating primary current and a telephone as indicator in the transverse circuit. He showed that the Hall coefficient, if it exists, does not exceed the value 5×10^{-9} , a magnitude nearly ten thousand times greater than that which theory indicates.*

The question of the existence of a true Hall effect in liquid electrolytes is therefore an open one. It seems probable, however, that such an effect exists, and that it is because the methods hitherto adopted to detect it have not been delicate enough that no satisfactory confirmation of the theory has been made.

Mr. H. L. P. Jolly, of Trinity College, placed his galvanometer, designed by Prof. Paschen, at my disposal, and I resolved to make an attempt to detect the effect indicated by theory. With the aid of such a delicate instrument it was hoped at least that the upper limit of the value of the Hall coefficient, 5×10^{-9} , obtained by Delvalez, would be considerably reduced.

The value of the expected effect will now be considered. If the potential gradient of the Hall effect along the z axis be denoted by $\partial e / \partial z$, and the potential gradient between the primary electrodes by $\partial \pi / \partial x$, then Donnan has shown that

$$\frac{\partial e}{\partial z} = \frac{\omega \epsilon}{L + M} (Lv - Mu) H \frac{\partial \pi}{\partial x}, \quad (1)$$

where H is the strength of the magnetic field, u and v are the velocities acquired under unit force by 1 grm.-mol. of positive and negative ionic matter, ω is the valency of each ion and ϵ is the quantity of electricity per gramme-equivalent of ionic matter. L and M are two factors depending for a partially dissociated electrolyte on the equilibrium equation

$$C = \phi(c),$$

and are connected with the concentration of the dissociated salt c and of the undissociated salt C , by the relations

$$L = \frac{2G\phi'(c)}{u} + 1, \dagger \quad M = \frac{2G\phi'(c)}{v} + 1.$$

Writing $\omega \epsilon u = U$ and $\omega \epsilon v = V$, where U and V are the velocities acquired by a gramme-molecule of positive or negative ionic matter under unit potential gradient, the coefficient of the Hall effect is

$$\frac{\partial e / \partial z}{H \partial \pi / \partial x} = \frac{LV - MU}{L + M}.$$

* Donnan, 'Phil. Mag.', 1898, vol. 46, p. 465; Larmor, 'Æther and Matter,' p. 301; van Everdingen, 'K. Akad. v. Wetensch. Amsterdam,' vol. 1, p. 27.

† G is the velocity acquired by 1 grm.-mol. of undissociated salt when acted on by unit force.

Donnan shows that the value of the Hall coefficient, assuming that the electrolyte is completely dissociated ($L = M = 1$) is

$$\frac{1}{2}(V - U) = 16 \times 10^{-13},$$

and the transverse potential difference due to it will be

$$e = 16 \times 10^{-13} Hz$$

for a fall of 1 volt per centimetre between the primary electrodes.

If $H = 15,000$ gauss and $z = 1$ cm., then

$$e = 2.4 \times 10^{-8} \text{ volt.}$$

Superposed on this effect is the difference of potential due to change of ionic concentration* and this is shown by Donnan to have the value

$$e' = \frac{1}{2}H(U + V)z \frac{\partial \pi}{\partial x}. \quad (2)$$

Taking $z = 1$ cm., and $\partial \pi / \partial x = 1$ volt per centimetre, we have, for a field of 15,000 gauss,

$$e' = 0.9 \times 10^{-7} \text{ volt,}$$

for a completely dissociated electrolyte. e' is larger than e . Nevertheless this potential difference, if it can be measured, will be as true an indication of the existence of a Hall effect as the potential difference e is. Further, on the above theory, the existence of e' implies that of e .

In the experiments described later it was found difficult to make observations within 15 seconds from the moment of exciting the magnetic field, so that probably the resultant of the two effects was observed.

It is impossible to measure the initial Hall effect, which is twice as large as the stationary Hall effect, because the stationary state has been reached by the time an observation is taken.

The effect arising from (1) will, in what follows, be referred to as the true Hall effect, while that arising from (2) will be called the concentration Hall effect.

Description of Apparatus and Method.

Fig. 1 is a diagram showing the arrangement of the apparatus. M, M are the pole pieces of the electromagnet and L is the liquid lamina placed between them. The primary circuit through the cell containing the liquid lamina is completed by the resistance R and the primary current is supplied by the battery B_1 .

The electromagnet circuit contained three rheostats R_1, R_2, R_3 , a reversing key K , and a Siemens-Halske ammeter A . A battery of 20 large cells supplied the current.

* *Vide* Donnan, *loc. cit.*, p. 468.

G represents the Paschen galvanometer. C is a control magnet fixed vertically above the galvanometer so that the sensitiveness could be varied by raising or lowering it, while the zero could be adjusted by turning it round. The distance from the electromagnet to the galvanometer was

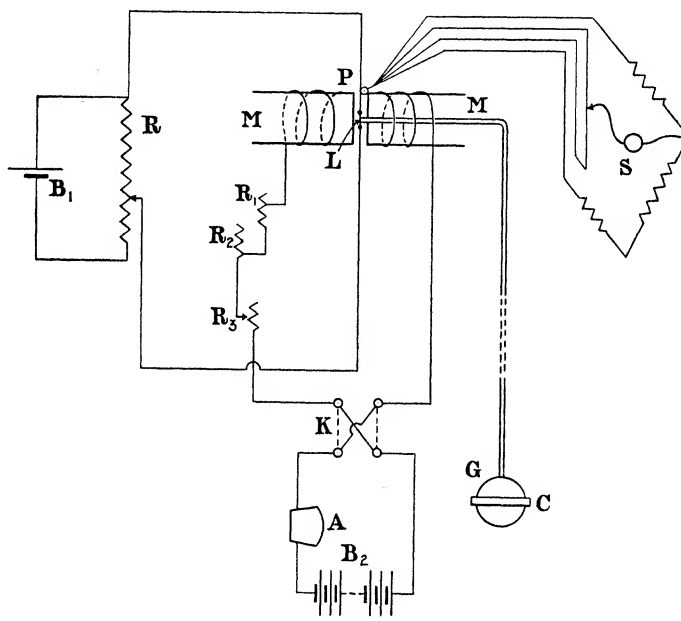


FIG. 1.

25 metres. At this distance the effect of the permanent field when the magnet was excited was small and varied from one experiment to another, depending upon the distance between the pole pieces and the intensity of the exciting current. Throughout an experiment this small change of zero remained of constant amount.

This form of galvanometer possesses advantages over the Broca galvanometer in that its period of swing for maximum sensitiveness is 7.5 secs. only, as compared with 17.3 secs., while its normal sensitiveness is 10 times that of the Broca galvanometer. The galvanometer was mounted on a stone slab supported by pillars which are built into the foundation of the Cavendish Laboratory. But during the day time the galvanometer zero was unsteady and therefore the observations were made at night. On one evening only were slight erratic disturbances noted, otherwise the zero was very steady.

The suspended system of the galvanometer consists of a fine glass rod about 8 cm. long, to the centre of which is attached a plane rectangular

mirror M (fig. 2). The system was made almost perfectly astatic by two groups of magnets M_1 and M_2 , each consisting of 15 small magnets fixed to the glass rod. The system was suspended by a fine quartz fibre, so that M_1 and M_2 each filled an oval-shaped cavity formed by a pair of coils. When all the four coils are connected in series, as in the present experiments, the resistance of the galvanometer is 16 ohms.

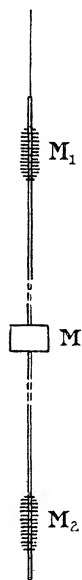


FIG. 2.

The Cells.—(a) *For Liquids*: The outside dimensions of the cell are $19 \times 19 \times 1.4$ mm. To construct one, a micro-square was taken and four small blocks of ebonite, cut from the same ring and approximately 1 mm. thick, were fixed at the four corners by specks of Canada balsam. A second micro-square was cemented to the tops of these, and three sides of the skeleton so formed were sealed with beeswax and resin. In fig. 3, b, b, b, b , are the ebonite blocks, P_1, P_2 , the primary electrodes of pure copper wire, and T_1, T_2 , the transverse electrodes of fine pure copper wire. The upper transverse electrode was movable and capable of fine adjustment.

(b) *For Copper Sulphate Gel*: A copper sulphate gel was prepared, placed upon the table of a microtome and frozen with ether. Thin sections of the gel were cut, thrown into water for a few moments, withdrawn and mounted on sheets of mica. The edges of the gelatine film were trimmed so as to form a square of about 2 cm. side. Fig. 4 is a diagram of the cell. The adjustment of the transverse electrodes

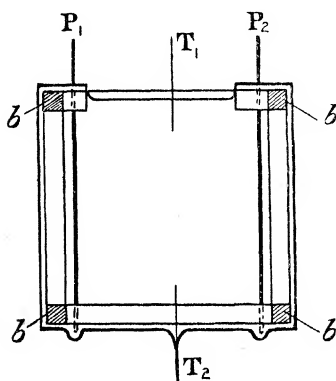


FIG. 3.

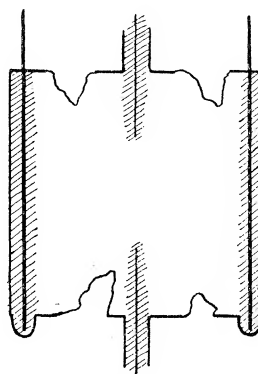


FIG. 4.

to the same equipotential was made by scraping away the gelatine. In order to secure good contact of the electrodes with the gel, the electrodes were laid in position on the microtome section and a layer of warm gel was

painted over them. The positions of the thicker layers of gelatine are shown by the shaded areas of the figure.

The type (a) of cell was mounted on a rigid brass support A (fig. 5), which was fixed to a heavy lead block B. The latter rested on a slate bed C, which had square rails screwed to it, and on these rails slid a brass carrier N, whose position could be adjusted by a screw motion. The movable electrode was attached to the glass rod S, and adjustments corresponding

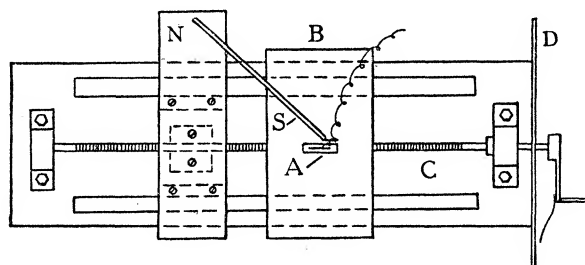


FIG. 5.

to $1/1800$ of the applied primary potential gradient could be made by moving the pointer over one division of the scale D.

A Grassot fluxmeter was employed to measure the intensity of the magnetic field and, with the search coil used, the full scale deflection corresponded to 22,300 gauss. The creep of the pole pieces was prevented by a wedge of brass.

To ensure that the temperature in the neighbourhood of the cell remained constant during an experiment, a small platinum thermometer was inserted just inside the gap. This thermometer was provided with compensating leads, and the temperature measured as shown at S (fig. 1).

A very small primary voltage was applied to the cell and the movable electrode adjusted or the equipotential lines twisted until the galvanometer gave a small deflection only. The primary potential gradient was now increased, and the same operations repeated until a voltage was reached beyond which the galvanometer zero was unsteady owing to irregularities in the action of the cell. The constancy of the zero was tested carefully in each case. The galvanometer circuit was now opened for a few seconds until induction effects due to the application of the magnetic field had died away, and the new zero of the galvanometer due to the presence of the magnetic field was noted. Several deflections were taken, each about 10 seconds after closing the galvanometer circuit. A similar series of observations was taken with the magnetic field reversed.

The importance of a uniform magnetic field cannot be overstated, for

minute motions of the electrolyte give rise to relatively large potential differences. Accordingly the cells were made much smaller than those which have been used hitherto, the area being about 4 sq. cm., whilst that of the pole pieces was 50 sq. cm. In all the researches referred to in the review of past work, the cells were of dimensions comparable with the size of the pole pieces. Further, in the present experiments the air gap was reduced as much as possible, not so much for the reason of creating a large magnetic field, although that is desirable, as for procuring a uniform field over the whole region occupied by the cell. Rarely were the pole pieces closer than 1 cm. in the experiments which have hitherto been made, and in some experiments they were as much as 2.5 or 3.0 cm. apart. In such cases it is most improbable that the magnetic field is uniform in the neighbourhood of the boundary of the cell, when a large cell is used, and consequently the salt begins to move up or down the gradient of the magnetic field according as it is paramagnetic or diamagnetic. This will give rise to motions of the fluid in the central part of the cell.

Chiavassa has shown that if we take a small cell and ensure that the magnetic field is uniform, then the effects found by the earlier experimenters entirely disappear. It is with the object of pursuing this question with a more delicate means of measuring the transverse effect that the present research was carried through. Differences of concentration throughout the cell are of secondary importance if the field is very uniform and so long as these differences remain constant. This is true, for instance, in a cell used vertically, as in the present experiments, where, through the action of gravity, the lower layer is more dense than the upper one.

To avoid disturbances due to air currents the cell was surrounded with pads of cotton wool and the junctions in the galvanometer circuit enclosed in glass tubes. The solutions were transferred to the cell by means of a capillary tube, and the presence of air bubbles thereby prevented. A syphon was provided in the later experiments to keep the cell full.

Experiments.

Copper Sulphate Solution.—An estimation by the iodine method was made and the solution was found to contain 13.3 gm. of copper sulphate per litre.

In the following table z_1 is the zero position on the scale when the galvanometer circuit is open, z_2 is the deflected position when the circuit is closed and the primary current is flowing, z_3 is the deflected position when, in addition, the magnetic field H is applied.

A preliminary experiment was made on March 15, 1912, the observations being taken to the nearest scale division only.

Field direct.

z_1 .	z_2 .	z_3 .	$d_1 = z_2 - z_1$.	$d_2 = z_3 - z_1$.	$d_2 - d_1$.	H.
7.0 7.0	6.0	7.0	-1.0	0.0	+1.0	0 +9900

March 16, 1912.—Field direct.

z_1 .	z_2 .	z_3 .	$d_1 = z_2 - z_1$.	$d_2 = z_3 - z_1$.	$d_2 - d_1$.	H.
19.0 19.0	18.0	19.0	-1.0	0.0	+1.0	0 +9900

Field reversed.

z_1 .	z_2 .	z_3 .	$d_1 = z_2 - z_1$.	$d_2 = z_3 - z_1$.	$d_2 - d_1$.	H.
20.0 20.0	22.5	21.0	+2.5	+1.0	-1.5	0 -9900

March 18, 1912.—The cell was washed out with copper sulphate solution and refilled. The following readings were taken :—

Field direct.

z_1 .	z_2 .	z_3 .	$d_1 = z_2 - z_1$.	$d_2 = z_3 - z_1$.	$d_2 - d_1$.	H.
20.3 *19.9 20.6	25.3 25.6	24.4	+5.0 +5.0	+4.5	-0.5†	0 +8000 0

* The alteration of the zero was produced by the fields of the electromagnet and the exciting circuit.

† The change of sign of $d_2 - d_1$ in this and the two following experiments, for a direct field, is due to a reversal of the galvanometer terminals.

Field reversed.

z_1 .	z_2 .	z_3 .	$d_1 = z_2 - z_1$.	$d_2 = z_3 - z_1$.	$d_2 - d_1$.	H.
21.6 19.6 19.7 21.9	25.2 25.4	23.5 23.8	+3.6 +3.5	+3.9 +4.1	+0.45	0 -8000 -8000 0

Temperature 18.3° C.

Field direct.

An examination of the tables given above shows that the approximate value of the deflection is 1 cm. for a field of 14,000 gauss. This value may be taken as indicating the true order of the effect. A calibration of the galvanometer showed that one scale division (*i.e.* 1 mm.) represented 5×10^{-11} ampère. The resistance of the cell between the transverse terminals was found to be 615 ohms and as that of the galvanometer is 16 ohms, the total resistance in the galvanometer circuit is 631 ohms. Hence 1 mm. on the scale represents 3.15×10^{-8} volt. A deflection of 1 cm. corresponds therefore to a transverse potential difference of 3.15×10^{-7} volt. The potential applied between the primary electrodes was 0.85 volt and as the distance between the electrodes is 1.5 cm., the primary potential gradient is 0.57 volt per centimetre. The distance between the transverse electrodes is 1.7 cm. From equation (1) we find, using these numbers, that the potential difference due to the true Hall effect will be 2.17×10^{-8} volt, while from equation (2) the accompanying Hall concentration effect will be 8.15×10^{-8} volt. This latter effect* is probably the one which has been measured, and the former, which would give rise to a deflection of one or two scale divisions, is included. These calculations are based on the assumption that the copper sulphate solution is completely dissociated, but whatever the extent of the dissociation the order of the calculated effect is the same as that of the experimental effect; for the function $\phi(c)$ is continuous and steadily increases with the concentration.

Although the large disturbing forces which gave rise to the effects observed by Bagard have been much reduced, there is still the possibility that the small effect in the present experiments may be due to a similar but far less effective cause. But if so, it is difficult to see how any effect due to arbitrary disturbances could give rise to such consistent results as those found. For not only was the liquid lamina changed for each experiment, the pole pieces were further apart in some cases than in others, and any erratic effect due to local disturbances would have had a good opportunity of showing itself, if it had existed. The effect observed appeared to grow for a short time but soon attained a steady value. It was impossible to observe the early stages of the deflection because several seconds were needed for the magnetic field to attain its steady value and on closing the galvanometer circuit a reading could be taken only after an additional 10 seconds had elapsed. When the magnetic

* It must be noted that in the calculation we have assumed that the solution is completely dissociated ($L = M = 1$). It can be shown that if $L \neq M \neq 1$, then $\frac{LV - MU}{L + M} > \frac{V - U}{2}$ because $V > U$. Hence the calculated value is too low. The solution contained 0.17 gm.-equivalent per litre, and was therefore by no means completely dissociated.

field was taken off, the deflection on closing the galvanometer circuit gradually became smaller.

At the suggestion of Sir Joseph Thomson, the following experiments were made on cells of copper sulphate gelatine in which movements of the solute as a whole are prevented. Drude and Nernst* have carried out experiments on gelatine laminae, and they found that the large effect observed by the early experimenters did not exist. Their means of investigation was not delicate enough, however, and it seemed interesting to test the above experiments on liquid copper sulphate by examining a gelatine film of the same salt.

To a strong solution of copper sulphate, estimated by the iodine method and found to contain 83 grm. of copper sulphate per litre, was added sufficient gelatine to enable thin sections to be cut. The gel contained 8 per cent. of copper sulphate by weight. Two cells of the type (*b*) were constructed, and an experiment made with each. The potential difference between the primary electrodes was 38 volts. The following observations were taken:—

May 6, 1912.—Field direct.

z_1 .	z_2 .	z_3 .	$d_1 = z_2 - z_1$.	$d_2 = z_3 - z_1$.	$d_2 - d_1$.	H.
45.3	42.1		-3.2			0
45.3	42.1		-3.2			0
45.3	42.0		-3.3			0
44.8		42.1		-2.7	+0.5	+15,000
44.4		41.7		-2.7		+15,000
44.7	41.7		-3.0			0

Field reversed.

z_1 .	z_2 .	z_3 .	$d_1 = z_2 - z_1$.	$d_2 = z_3 - z_1$.	$d_2 - d_1$.	H.
45.1	42.5		-2.6			0
45.0	42.4		-2.6			0
44.7		41.7		-3.0		-15,000
44.9		41.6		-3.3	-0.5	-15,000
45.1	42.3		-2.8			0
45.0	42.4		-2.6			0

Temperature 17.6° C.

* 'Wiedemann Ann.,' 1891, vol. 42, p. 568.

May 7, 1912.—Field reversed.

z_1 .	z_2 .	z_3 .	$d_1 = z_2 - z_1$.	$d_2 = z_3 - z_1$.	$d_2 - d_1$.	H.
40·0	25·6	24·5	—14·4	—15·0	—0·65	0
39·9	25·5		—14·4			0
39·9	25·6		—14·3			0
39·5	25·6		—14·3			—15,000
39·9						

Field direct.

z_1 .	z_2 .	z_3 .	$d_1 = z_2 - z_1$.	$d_2 = z_3 - z_1$.	$d_2 - d_1$.	H.
39·9	26·0	26·8	-13·9	-13·6	+0·43	0
39·85	25·9		-13·95			0
39·8	25·9		-13·9			0
40·4						
39·9	25·9		-14·0			0
39·8	25·8		-14·2			0
39·8	25·6		-14·2			0

Temperature 17·5° C.

The thickness of the laminae in the last two experiments was 30 μ . From the tables it is seen that a deflection of 5 mm. was found on applying a magnetic field of 15,000 gauss. This deflection disappeared within a minute from taking off the magnetic field. The sensitiveness of the galvanometer was tested and 1 mm. was found to correspond to 1.5×10^{-10} ampère. The resistance of the lamina between the transverse electrodes was 2300 ohms, and therefore 1 mm. deflection corresponds to 3.5×10^{-7} volt. Hence the magnitude of the transverse effect is 17.5×10^{-7} volt. Using (1), where $\partial\pi/\partial x = 38/2.3 = 16.5$ volts per centimetre, $H = 15,000$ gauss, $z = 0.5$ cm., we find that the transverse potential difference is 19.8×10^{-8} volt; while (2) gives a transverse potential difference of 7.4×10^{-7} volt.

Experiments on (a) Silver Nitrate Solution, (b) Cadmium Sulphate Solution.—

(a) A solution containing 10 per cent. of silver nitrate was used. This was contained in a cell made of mica, the inside dimensions of the cell being 2.6 cm. $\times$ 1.8 cm. $\times$ 0.05 cm. The primary electrodes were of silver, 0.05 cm. diameter; the transverse electrodes, also of silver, had a diameter 0.063 mm. The cell was mounted on a large sheet of mica which was fastened to one pole piece of the electromagnet.

The following readings were taken :—

May 25, 1912.—Field direct.

z_1 .	z_2 .	z_3 .	$d_1 = z_2 - z_1$.	$d_2 = z_3 - z_1$.	$d_2 - d_1$.	H.
30·3	27·6		-2·7			0
30·3	27·6		-2·7			0
30·6		28·5		-2·1		+14,800
30·6		29·0		-1·6		+14,800
30·6		29·1		-1·5	+1·0	+14,800
30·6		28·9		-1·7		+14,800
30·6		28·9		-1·7		+14,800
30·3	28·5		-1·8			0
30·3	28·5		-2·3			0

Field reversed.

z_1 .	z_2 .	z_3 .	$d_1 = z_2 - z_1$.	$d_2 = z_3 - z_1$.	$d_2 - d_1$.	H.
30·3	27·8		-2·5			0
30·3	27·8		-2·5			0
29·8		27·0		-2·8		-14,700
29·8		26·1		-3·7		-14,700
29·85		26·0		-3·85	-1·1	-14,700
29·9		26·0		-3·9		-14,700
29·85		26·1		-3·75		-14,700
29·85		26·1		-3·75		-14,700
30·3	26·9		-3·4			0

Temperature 18·6° C.

The deflection observed on applying a field of 14,800 gauss was 10 mm. The resistance of the cell between the transverse electrodes was 1200 ohms, and as 1 mm. deflection corresponded to 1.5×10^{-10} ampère, the value of the transverse potential difference is 1.8×10^{-7} volt. The primary potential gradient was 0.63 volt per centimetre, and the transverse electrodes were 2.1 cm. apart. From these data the calculated value* of the transverse potential difference, assuming it to be a Hall concentration effect, as represented by (2), is 1.24×10^{-7} volt.

(b) A 15-per-cent. solution of cadmium sulphate was prepared. The dimensions of the cell were 1.4 cm. $\times$ 2.35 cm. $\times$ 0.09 cm., and the electrodes were of cadmium wire drawn out to convenient thicknesses, the diameter of the primary electrodes being 0.08 cm., that of the transverse electrodes 0.035 cm.

The following readings were taken :—

* The values of (V+U) for copper sulphate solution, silver nitrate solution, and cadmium sulphate solution are each equal to 12×10^{-4} cm./sec. for a potential gradient of 1 volt per cm.

October 23, 1912.—Field direct.

z_1 .	z_2 .	z_3 .	$d_1 = z_2 - z_1$.	$d_2 = z_3 - z_1$.	$d_2 - d_1$.	H.
26.5 25.9 26.5	26.1 26.2	26.7	-0.4 -0.3	-0.8	+1.15	0 +11,400 0

Field reversed.

z_1 .	z_2 .	z_3 .	$d_1 = z_2 - z_1$.	$d_2 = z_3 - z_1$.	$d_2 - d_1$.	H.
26.5 27.0 26.5	28.2 28.2	28.5	+1.7 +1.7	+1.5	-0.2*	0 -11,400 0

Temperature 17.2° C.

* The unequal values of $(d_2 - d_1)$ are probably due to a small diffusion effect which would not reverse with the magnetic field.

The deflection obtained on applying a field of 11,400 gauss was 7 mm. The resistance between the transverse electrodes was 220 ohms and as 1 mm. deflection was found to correspond to 1.6×10^{-10} ampère, the transverse potential difference is 3.52×10^{-8} volt. The distance between the transverse electrodes was 2 cm. and between the primary electrodes 1.2 cm. and the primary voltage applied was 0.55. Using these data in (2), the calculated value of the transverse potential difference is 7.5×10^{-8} volt.

Conclusion.

In the above experiments the Hall concentration effect contributes the greater part of the potential difference, and the true Hall effect, which would give rise to a deflection of 1 or 2 mm., is included. It was hoped at the outset that some information as to the nature of the process of reversal would be obtained by an examination of electrolytes whose differences of ionic velocities vary considerably. But the preponderance of the concentration effect, depending on the sum of the ionic velocities, has prevented this. Eight experiments have been made and all the potential differences are of the calculated order, they reverse with the magnetic field and act in the same direction, while the experimental conditions vary widely. These results are regarded as establishing the existence of a Hall effect in liquid electrolytes.

[*Note added January, 1913.*—The observations on copper sulphate solution are plotted in fig. 6. For low magnetic fields (8000 gauss) the error of

observation amounts to 20 per cent. of the total deflection. This error is attributed to disturbances in the cell. The point A departs from the linear relation by 27 per cent., while the point B is approximately 10 per cent. out. The points C and D correspond to a field of 14,000 gauss and the error of observation is smaller. The mean positions of the pairs of points A-B and C-D are marked Δ , and these lie approximately on a straight line passing

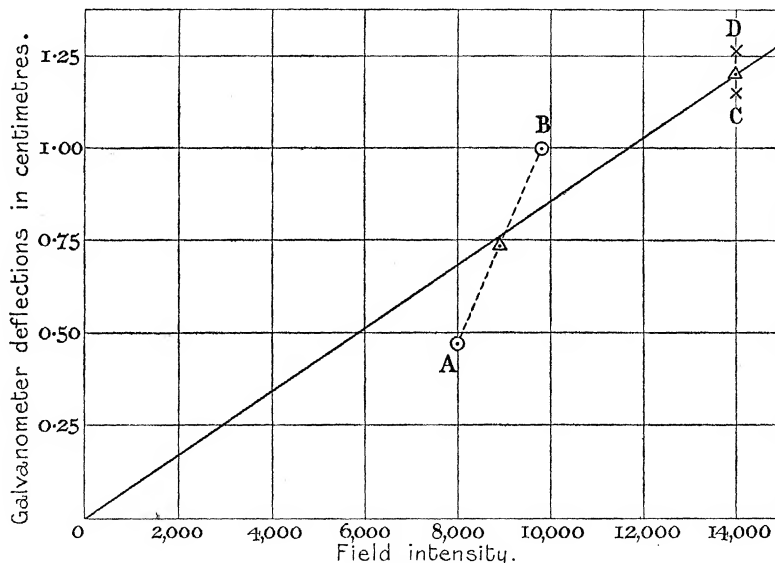


FIG. 6.

through the origin. Hence within the limits of experimental error the transverse potential difference is proportional to the magnetic field. It has been shown by Florio that the proportionality of the magnetic field and the large effect observed by Bagard may be due to the presence of vortical motions in the solution, and for this reason more reliance is placed on the uniformity of the effects observed and on the quantitative agreement with theory, in identifying the Hall effect, than on showing that a linear relationship exists between the magnetic field and the effect.]

The above experiments were made in the Cavendish Laboratory between October, 1911, and November, 1912.

I wish to express my indebtedness to Sir Joseph Thomson for advice and criticism during the progress of this research and to Mr. H. L. P. Jolly for the loan of the galvanometer.